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CURRENT PERSPECTIVES ON AQUATIC EFFECTS OF ACID RAIN IN NOVA SCOTIA

SEPTEMBER 1982

J. G. Kerr, Minister

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SUMMARY

1. The pH of rain and snow in Nova Scotia averaged 4.6 during the interim 1977 through 1980. Measurements made almost 30 years ago averaged 5.7. While climatic variability may be responsible for some of the difference, there is good evidence for an intensification of acid precipitation over the past 25-30 years in northeastern North America.

2. In rural Nova Scotia, the atmospheric deposition of non-marine sulphur and nitrate nitrogen amount to 50700 and 22600 tonnes per annum (wet plus dry deposition).

3. Over 50 percent of S and NO_3 (as N) deposition occurs as sulphuric acid and nitric acid, respectively. As such, 67300 tonnes of H_2SO_4, and 36900 tonnes of HNO_3 are deposited on rural areas of the province each year.

4. In general, 80% of sulphur deposited is transported into the province.

5. The southwest interior of the province, considered the most sensitive to acidification, receives 95% of the non-marine sulphur from other jurisdictions.

6. Of sulphur transported into Nova Scotia, 70 to 75% originates in the United States.

7. By itself, acidic deposition in rural Nova Scotia is not considered to be of sufficient magnitude to cause acidification of surface waters.

8. As a corollary, the relative importance of natural acids formed in soils and bedrock in the acidification of surface waters in the province has not been thoroughly examined.

9. Reductions in salmon populations in 22 Nova Scotian rivers are the current biological effects attributed to acidification processes in rural areas of the province. Changes in fish populations of lakes have not been recorded. However, it should be recognized that the historical data record

for fish populations in lakes is sparse. Preliminary data on freshwater algae sensitive to acid do not indicate that lake acidification has occurred to a significant degree.

10. There is abundant research to demonstrate that lake acidification has occurred in the Halifax area. This is attributed to combustion of petroleum products which contain metal catalysts which increase the rate of conversion of gaseous sulphur dioxide (SO_2) to water soluble and acid forming sulphur trioxide (SO_3).

11. While coal combustion could theoretically increase the emissions of SO_2 in Nova Scotia, emissions of SO_3 would be relatively lower than in oil-fired plants. As such, atmospheric dispersion processes would more effectively prevent near-field effects.

12. There is little evidence to link development of Nova Scotian coal resources with impingement of atmospheric emissions on other regions.

CURRENT PERSPECTIVES ON EFFECTS OF ACID RAIN IN NOVA SCOTIA

INTRODUCTION

The Nova Scotia Department of the Environment has conducted a study of the chemistry of precipitation falling on Nova Scotia since 1977. The study has yielded information on quantities of minerals, nutrients, and acids in rain, snow, and dust. The survey was designed* with an effort to avoid biasing results with local emissions of atmospheric contaminants. Site locations are shown on Figure 1, which also shows pH isopleths for weekly catches during the period Fall 1977 through 1980. Figure 1 differs slightly from data presented previously (Underwood, 1981) in that the pH gradient is not so steep. This is not considered to be a significant trend, and may be explained by a careful examination of differences in sample handling and data evaluation. For example, the location of the northern Cape Breton station was moved in 1979 to a site more accessible during winter months. This permitted a reduction in the number of bulk samples during the snow season, has increased the ratio of wet-only samples, and decreased the sampling interval from an average of 24 days to 7 days.

The average pH of rain and snow falling on the province is now 4.6. The only known historical reference is from 30 years ago when pH at Kentville, on the Bay of Fundy coast, averaged 5.7 (Herman and Gorham, 1957). Climatic variability is

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* Instruments used were Sangamo type wet/dry samplers, common to many Provincial and Federal networks in Canada.

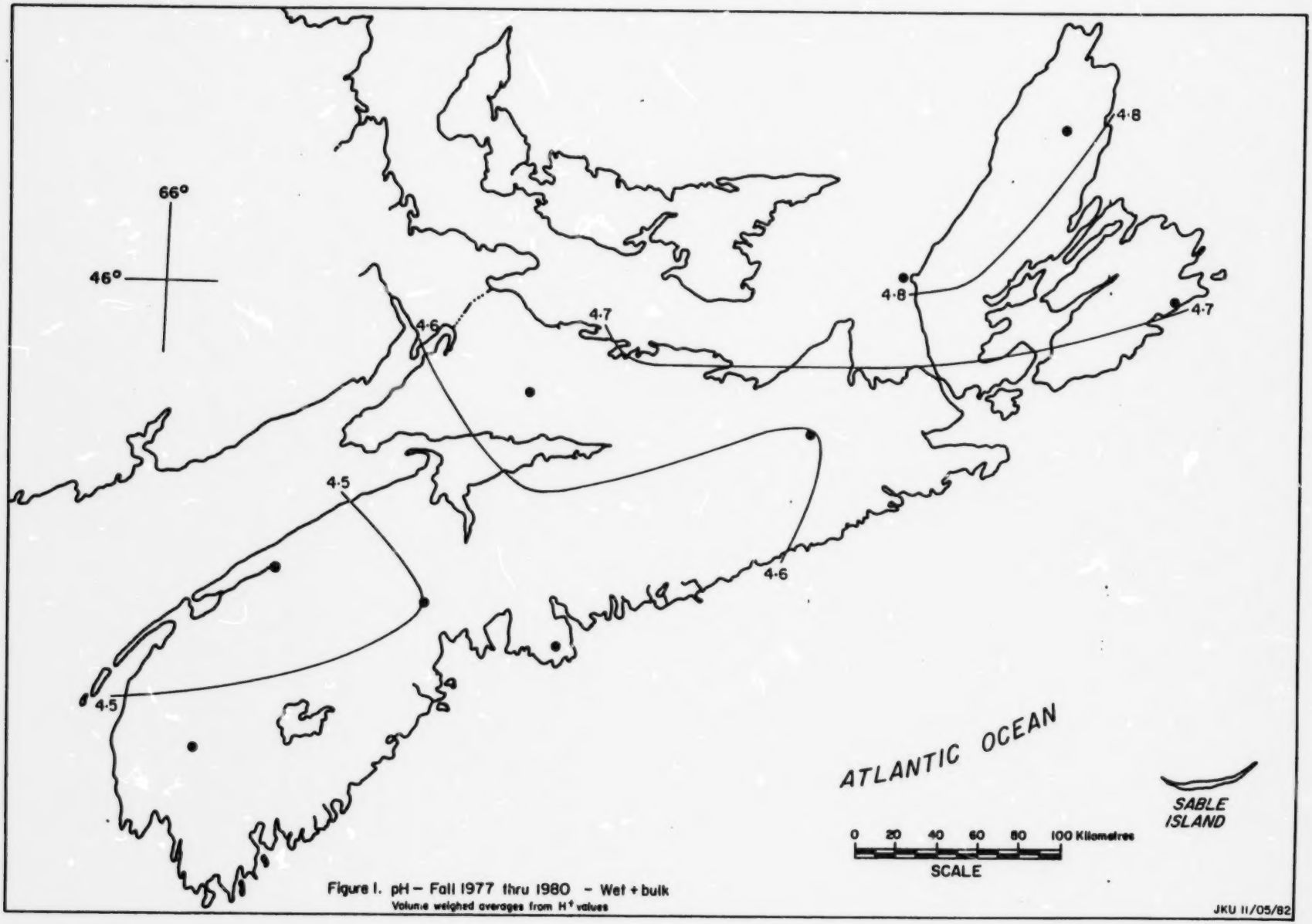

Figure 1. pH – Fall 1977 thru 1980 – Wet + bulk
Volume weighed averages from H^+ values

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known to influence the pH of precipitation (Stensland, 1979 and should be carefully examined prior to interpolation between the two study periods. However, Likens and Butler (1981) present evidence for intensification of acidity in northeastern regions of the U.S. since 1956, results that seem consistent with data from Nova Scotia.

It is not the intent of this discussion to dwell upon the deposition of acid rain, for the presence of this environmental concern in Nova Scotia is well established (Freedman and Ogden, 1981; Underwood, 1979, 1981; Vaughan et al., 1982; Wiltshire, 1979; and Shaw, 1979). Values for annual deposition of sulphate, nitrate nitrogen, and hydrogen are presented to provide an update on earlier work (Underwood, 1979), however the main purpose for the following is to examine evidence for perceived consequences of the deposition of atmospheric acids in Nova Scotia.

CURRENT ESTIMATES FOR THE DEPOSITION OF S, N, AND H^+ ON NOVA SCOTIA

Table 1 shows annual deposition of non-marine sulphate, nitrate nitrogen and hydrogen ions on rural Nova Scotia. Average concentrations of sulphate, nitrate and hydrogen are shown for reference, as are ratios of selected ion combinations. It is estimated that 54% of wet deposition of SO_4 & NO_3 occurred as H_2SO_4 and HNO_3 such that the annual deposition of these acids is 104200 metric tonnes on rural areas of Nova Scotia. Total deposition of S and NO_3 (as N) in rural areas amounts to 63900 and 22600 tonnes respectively when dry deposition is also considered.

Shaw (1982) presents evidence that sulphur emissions from the Halifax area are adding to atmospheric sulphur transported to the province from distant emission sources. His estimates are that 1.87 g S/m^2-yr measured at the Head of St. Margaret's Bay

TABLE 1: ANNUAL DEPOSITION OF SULPHUR, NITROGEN AND HYDROGEN ON RURAL NOVA SCOTIA

WET* DEPOSITION

	Tonnes		mg/L
Marine plus non-marine sulphur	138000 as SO_4	46000 as S	1.83 as SO_4
Non-marine sulphur	109400 as SO_4	36500 as S	1.45 as SO_4
Acid sulphur	67600 as SO_4	22500 as S	0.90 as SO_4
Nitrate nitrogen	54900 as NO_3	12400 as N	0.16 as N
Acid nitrate	35700 as NO_3	8100 as N	0.10 as N
Hydronium ion	1860 as H^+		0.025

Acid S: Acid N = 2.78 Acid S: Total S = 0.49 Acid N: Total N = 0.65

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* Using wet/dry precipitation collectors, Wet ÷ (wet & dry) = 72% for S and 55% for NO_3-N. Thus total deposition of S=63900 tonnes, while total deposition of NO_3-N is 22600 tonnes.

can be attributed to Halifax area emissions, and he suggests that a higher than background deposition rate could be found within 30 to 40 km or 30 to 50 km from Halifax. With a 35 km radius on the zone of influence, the metro area (Halifax, Dartmouth, Bedford, Sackville) would receive an additional 7200 tonnes of S per annum; about 33% of metro area emissions in 1980. Applying the same ratios to the three other major emission areas in the province, and adjusting for that fraction that falls on land only yields the following estimates:

SOURCE AREA	TONNES S DEPOSITED WITHIN 35 KM RADIUS	LAND FRACTION OF AREA INFLUENCED	DEPOSITION (TONNES S)
Halifax-Dartmouth	7200	0.55	3960
Pictou Trenton	4674	0.60	2800
Canso Area	4885	0.59	2870
Sydney - Lingan	7500	0.41	3080
TOTAL			12710

A consideration of sulphur deposition in Nova Scotia would therefore indicate that for a non-marine sulphur deposition of 63400 tonnes, provincial emissions could contribute about 20%. This may represent an over-estimate, for the Halifax emissions are influenced by oil-fired thermal generating stations which contain trace catalysts (like nickel and vanadium) which enhance rapid conversion of a portion of the SO_2 to SO_3 and hence increase local redeposition of sulphur. The other regions contain either coal-fired or a mixture of coal and oil-fired thermal generating stations in

addition to additional industrial commercial and residential emission sources. Ash associated with coal-fired stations usually adsorbs and neutralizes acids formed from SO_3 that may be present. Thus, stack emissions of sulphur from these plants are primarily in the form of SO_2.

The area of the province most frequently cited as exhibiting signs of acid stress is to the southwest of major emission sources in the province. Kejimkujik National Park was considered representative of the region by the Atmospheric Modeling and Deposition Work Group (#2) of the Memorandum of Intent scientific advisors. Averages of several models that were described resulted in the following estimates for sources of emissions that impinge on S.W. Nova Scotia (from MOI, 1981).

SOURCE AREA (MOI NUMBERS)	% OF DEPOSITION IN S.W. SCOTIA
1. Michigan	6
2. Illinois, Indiana	5
3. Ohio	10
4. Pennsylvania	8
5. New York to Maine	27
6. Kentucky, Tennessee	2
7. N. Virginia to N. Carolina	7
8. Rest of eastern USA	4
9. Ontario	9
10. Quebec	11
11. Atlantic Provinces	10

Of interest is that while approximately 70% of the deposition is attributed to the U.S.A., the oft-quoted Ohio is not the largest contributor. Emissions from New York through Maine share that dubious honour.

If Nova Scotia and New Brunswick are weighted equally with respect to sources for sulphur deposited in S.W. Nova Scotia (their annual emissions are comparable) then it may be postulated that 95% of the sulphur deposition in that area of the province the most sensitive to acidification, is imported. A consideration of sources and sinks for nitrogenous emission products is currently not possible. While emission inventories do exist, chemical pathways in the atmosphere are less well known, and modeling efforts are, at best, preliminary.

BIOGEOCHEMICAL SETTING AND IMPORTANT TERRESTRIAL FEATURES

Except for 30 to 40 km of boundary shared with New Brunswick, Nova Scotia is completely surrounded by water. This factor has heavily influenced the population distribution in the province, for many of the 812,200 residents live within a 20 kilometers of this coast. Figure 2 shows locations for all communities with a population of over 1000. These communities comprise 50% of the population of the province. The major potential emission sources for air pollution are also shown on Figure 2.

Residential requirements of this rather sparse population, together with areas currently used for agriculture account for only 8% of the land area of the province. The remaining 92% is covered with the forest or wet lands. The forests struggle on what soils and nutrients remained following glacial processes during the Pleistocene Epoch, and more recently, heavy lumbering activities for shipbuilding during the 19th Century, and pulp harvesting during the present century. Thus, many nutrients literally sailed from our shores, while others were lost with erosion that resulted from the process of timber harvesting itself.

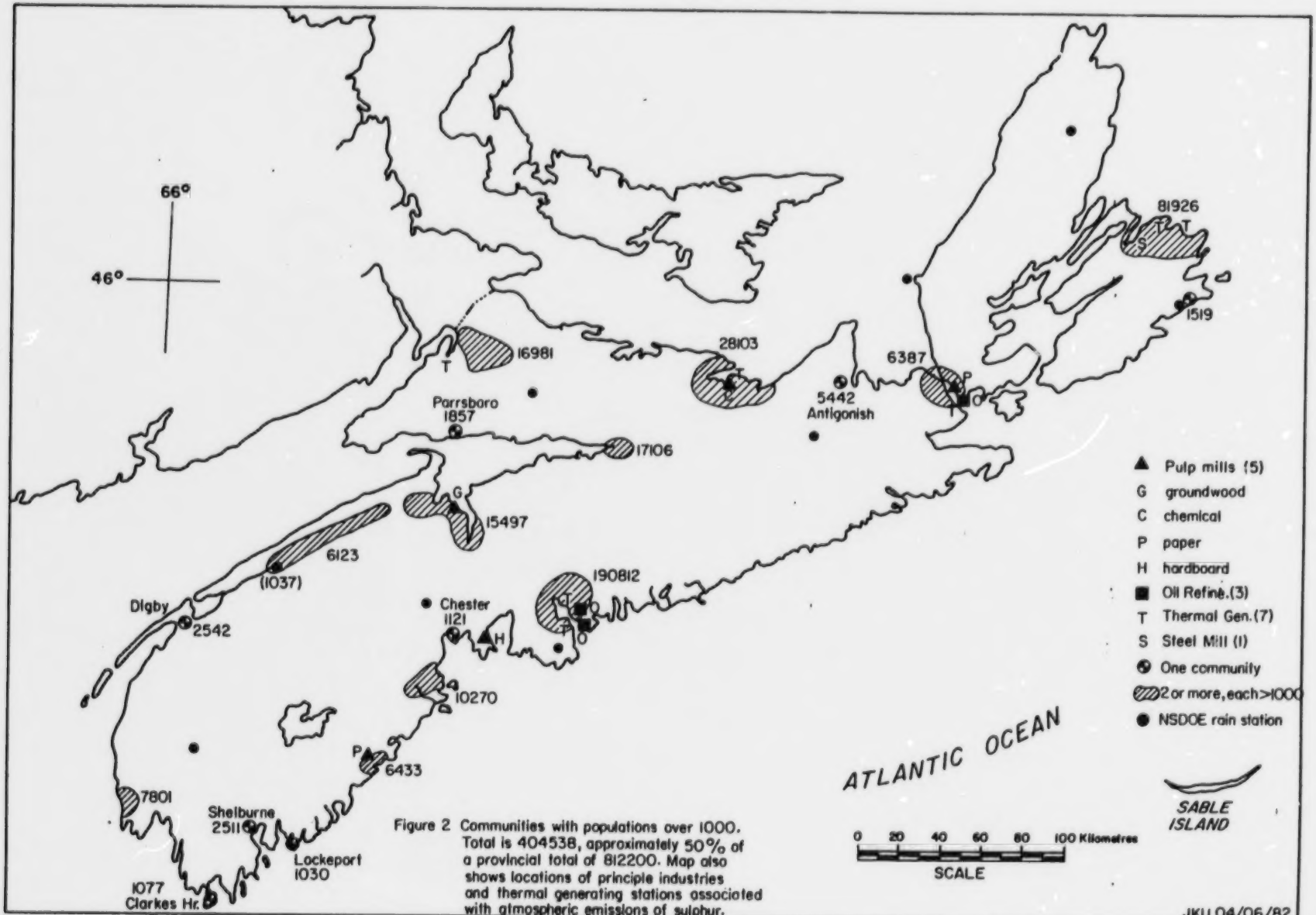

Figure 2 Communities with populations over 1000. Total is 404538, approximately 50% of a provincial total of 812200. Map also shows locations of principle industries and thermal generating stations associated with atmospheric emissions of sulphur.

In addition, much of the province is underlain by bedrock which the Geological Survey of Canada (Shilts, 1981) classifies as potentially "High or High-intermediate" sensitivity with respect to the capacity to neutralize acidic deposition. This implies that weathering processes do not rapidly provide large quantities of dissolved minerals, and Hilchey (1972) goes so far as to suggest that 80% of the province should be considered non-agricultural.

With the understanding that 82% of the forest land is either predominately softwood (53%) or mixed growth (29%), it is proposed that non-agricultural areas of the province are covered mainly with softwood stands, with lesser amounts of mixed stands and wetlands.

Softwood leaf litter, and ion exchange processes of wetlands produce natural organic acids that impart a high organic carbon content, and measureable acidity to water. In addition, softwood trees generally have roots which do not penetrate deeply into soils to raise unweathered nutrients supplies, and their needles do not recycle minerals effectively via decomposition pathways. Thus, soil horizons are thin, and deficient in neutralizing minerals. Furthermore, oxidation of sulphur compounds in the soils, and in selected exposed mineralized bedrock (e.g. pyrites in Meguma slates; Thompson, 1978) can lead to the production of sulphates which, in absence of mineral cations like calcium, may bond with H^+ to form sulphuric acid. Thus, at least 77% of the province is covered with soils that are too poor for agriculture and receive acids which are generated on or in the soils. These acids can participate in the acidification of surface waters, and must be considered in thorough assessments of effects of acid rain.

The relative importance of natural versus anthropogenic acids, and the cumulative effects of each have received little study although some preliminary data from a

federal study in Kejimkujik National Park indicate that naturally produced acids can in theory equal or exceed acid deposition by precipitation. (Oliver and Slawych, 1981).

By themselves, natural acids are capable of maintaining lake and river pH around at least the low 4's and many water bodies in the province have most likely exhibited low pH levels for many years. Fossil evidence in lake sediments from Kejimkujik Lake has even indicated that during the period 1680 to 1850, conditions were more acidic than at present (Delorme, 1981). So long as pH levels remain relatively constant, aquatic communities are produced for which such conditions are optional for growth. Preliminary information on diatom populations in acidic brown-water lakes from rural southwestern Nova Scotia indicate higher than expected diversity indices.

When one considers atmospheric deposition of acids, the present indications are that by itself the background or rural level of acid rain is not sufficient to acidify these aquatic environments. However, there is evidence that when the two acid sources are compounded, acidification can and does occur.

Watt (1981) reports a reduction of both pH and alkalinities in several rivers in the province for which there are reliable historical data from 1954 - 1955. Preliminary data from Kejimkujik Park indicate reductions in alkalinities in some lakes during the past ten years although pH levels have not fluctuated so markedly. Wiltshire and Machell (1981) have reported preliminary results for 16 lakes in Nova Scotia and New Brunswick and commented that 13 lakes showed reductions in pH and alkalinities. However, results from subsequent samples demonstrated that levels were not so low as the 1979 samples. This indicates seasonal and climatic variations must be considered when trend analysis is conducted.

BIOLOGICAL EFFECTS

In the summer of 1980, a federal fisheries survey indicated that of all salmon rivers in Nova Scotia, nine had no juvenile salmon and were considered extinct of salmon runs, 13 were expected to exhibit some mortality especially to juvenile fish, a further nine were considered threatened although there were no signs of diminished populations, and the remaining rivers were considered to be in no danger (Watt, 1981). The interpretation offered was that increases in acidity could account for changes noted, although the author cautions that many other environmental problems are threatening Atlantic salmon populations : industrial pollution, poor forestry practice*, careless road construction and excessive harvesting of the fish both legal and illegal, and both within the rivers or along the coast adjacent to river mouths.

The majority of the rivers reported as devoid of salmon, or threatened, are found in the area of the province which also contains the greatest number of wetland sites. This observation is not only apparent from an examination of appropriate maps, but is also reflected by Farmer et al., (1981) who comment that the rivers are naturally acidic and of low productivity, although they historically sustained Atlantic salmon populations. Fish records for the Clyde River indicate no salmon have been caught since 1971. The authors note that pH has declined below 5.0 since 1954 - 1955, and that barriers to salmon migration have not, to their knowledge, existed. Records for the period 1936 to 1955 show a total of 737 salmon captured; about 37 fish per year (Farmer et al., 1981). Although evidence linking the disappearance of salmon to acidification of the river is circumstantial, it is

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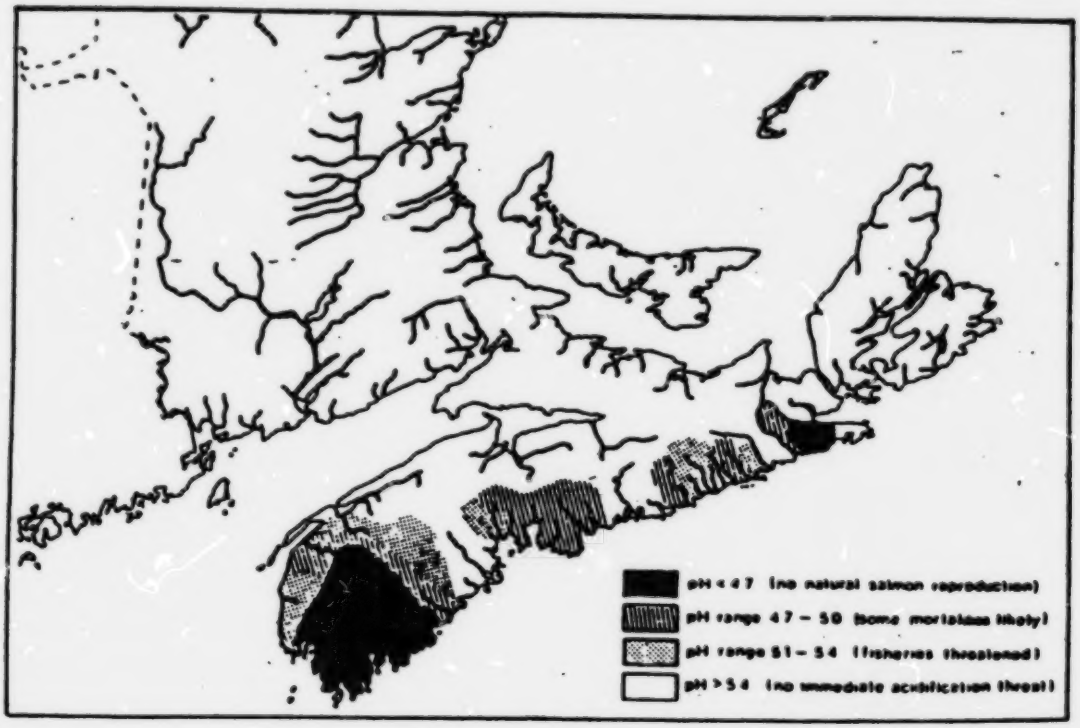
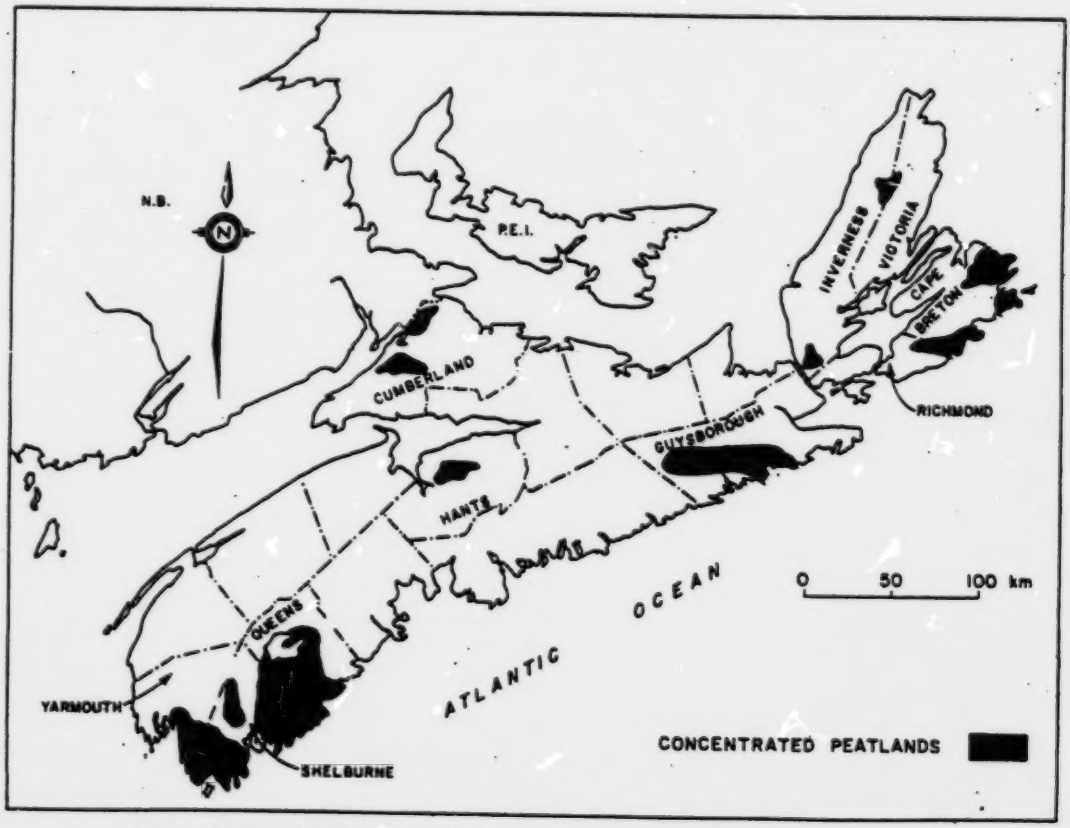
* Siltation of stream beds by soils stripped of vegetation, alteration of water courses for the purposes of floating and transporting timbers (damming and straightening of channels as part of a process called stream driving), interruption of natural processes for retaining minerals in soils for recycling (intensified leaching of ash and exposed soils .





Areas devoid of natural salmon reproduction (Watt, 1981) compare closely with the concentrated peatlands of Nova Scotia (N.S. Mines & Energy, 1982). This implies that natural acidification processes must be considered along with acidic precipitation when assessing biological effects.

compelling. However to suggest that acids in precipitation have been the prime reason for river acidification requires some additional substantiation. For example, during the period 1945 to 1970, precipitation in Atlantic Canada has increased by an average of 7%. Based on the 1404 mm measured during the Nova Scotia Department of the Environment study, this would amount to almost 100 mm or 5.3×10^{12} litres of extra precipitation to moisten soils in the province for optimal oxidation of sulphur compounds therein; to increase the flushing of natural organic acids from wetlands; and to reduce the possibilities for entraining calcareous dust in air masses. A thorough analysis may show these points to be of secondary importance, although this thorough analysis has not appeared in published form if it has been done.

Spot surveys of over 100 lakes in the south western portion of the province have indicated that lake acidification is not occurring so quickly as river acidification. It is proposed that water residence time is very important : acidic runoff is retained in lake basins for a sufficient time period to permit either contact with calcareous lake sediments (average 1500 ppm as calcium) or "recharging" with bicarbonate as a result of metabolic processes in aquatic organisms.

Chemical results indicate very low bicarbonate buffer capacities although some studies on acid sensitive algae would suggest that acidification processes have yet to create changes in the algal communities studies.

It should be mentioned that 66 lakes in the spot sample study were also surveyed with shore set gill nets and minnow traps. The nets and traps were placed at two or three locations around the margin of each lake for a day, and resulted in the capture of fish from all but three lakes. A re-examination of the three lakes is proposed for the summer of 1982.

Fluctuations in lake chemistry are apparent from season to season and year to year, a climatic process that creates background "noise" which makes trend analysis difficult. Therefore, analyses of short-termed trends must fully consider relative scales of the natural fluctuations.

URBAN EFFECTS NOTED

Thus far, discussion has been directed toward rural areas of Nova Scotia. As noted earlier, urban areas, particularly metropolitan Halifax-Dartmouth, must be considered zones of special interest. It has been suspected for some time that urban emissions in the metro area are contributing to background acid deposition in sufficient quantities that lake acidification has occurred (Vaughan et al., 1981; Watt et al., 1979). The data are reasonably clear from both chemical and biological perspectives, and Shaw (1982) has discussed trajectory analysis that would lend further substance to the hypothesis. In the case of urban acidification it would seem that atmospheric loading of acids is by itself sufficiently intense to cause problems in even clear-water local lakes where organic acids are not present.

Watt (personal communication) has conducted some neutralization studies in one clear lake in order to control the rate of acidification. The Nova Scotia Department of the Environment has chosen to examine problems associated with liming coloured-lakes. Results of both studies are pending.

ATMOSPHERIC DEPOSITION OF ACIDS IN PERSPECTIVE

In summary, deposition of atmospheric acids in most areas of Nova Scotia would not appear to be of sufficient magnitude to independently create measurable effects.

However, when accompanied by additional natural or cultural stresses, acid rain can be associated with significant biological changes in lakes and rivers in the province. Deposition of wet sulphate is between 20 and 25 kg/ha-yr in the south-west portion of the province and this is in excess of target loadings suggested by MOI Work Group I as being protective for a majority of surface waters. Reasons for concern are clear and valid. It remains to quantify rates that may be associated with acidification processes, and to determine the relative proportions of natural and cultural acid loadings in rural and urban areas of the province.

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